STATUS REPORT

COMMITTEE ON SST-SONIC BOOM

NATIONAL ACADEMY OF SCIENCES

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STATUS REPORT
COMMITTEE ON SST-SONIC BOOM

SUMMARY CONCLUSIONS

1. Moving into the next phase of SST development is clearly warranted by the evidence from research, tests, and studies of sonic boom phenomena. While no insuperable sonic boom problems have been disclosed, and while many aspects of the sonic boom are reasonably well understood, there are some aspects, notably in the public acceptance area, where much more information is needed.

2. Recent encouraging evidence of progress by NASA in research on the generation and propogation of sonic booms emphasizes the need for intensive, continued effort in that area and on aircraft design techniques for reducing or making more acceptable the effects of sonic booms. Research on effects of booms on animate and inanimate objects must continue, with special effort on obtaining information that will bridge the gap in knowledge between booms generated by the relatively small aircraft that have been tested and those from the SST. Such actions as getting measurements from B-70 test flights and from the B-58 training flights should be taken immediately.

3. It can be stated with confidence that at the sonic boom intensities anticipated for the SST, there will be no significant, direct physiological effects on people.

4. At the sonic boom intensities anticipated for the SST, physical damage to structures that are reasonably well designed and constructed will be essentially negligible and will occur mainly when conditions are such that the sonic boom can trigger a reaction resulting in damage.

5. In the psychological area, particularly in relation to public acceptance of repeated and continuing sonic booms, there are few basic data on which to base firm conclusions. Neither is it clear what research techniques might obtain better data or to what extent confident predictions might be made from them. For example the extent of minor claims for real or imagined damage is very difficult to predict. Major effort is needed to evaluate these problems.

INTRODUCTION

In May 1964, acting on the advice of the President's Advisory Committee on the Supersonic Transport, President Johnson requested the National Academy of Sciences to provide guidance on an expanded program for studying the sonic boom and the effects that would result from operation of a supersonic transport. Accordingly, Dr. Frederick Seitz, President of the Academy, established the Committee on SST-Sonic Boom under the chairmanship of Dean John R. Dunning, School of Engineering and Applied Science, Columbia University.

The Committee itself has formed special panels in several areas in order to provide expert knowledge in all the areas that are involved. Thus, a panel of architects, engineers, those with experience in the use of explosives and those with knowledge of major structural materials has examined the area of structural response. Similarly, an insurance panel, composed of the major airline underwriters, has examined the projected effect on airline insurance costs from operation of supersonic aircraft.

The National Academy of Sciences has also utilized established units within the Academy in problem areas important to sonic boom considerations. Arrangements have been made with the Building Research Advisory Board and the Committee on Hearing and Bio-Acoustics to provide both staff and consultant services on the structural and material effects and the physiological effects, respectively. Each of these groups is examining the sonic boom question and has submitted the preliminary results of their examinations to the Committee on SST-Sonic Boom for inclusion in this report. Each unit had previously prepared guide lines for the sonic boom testing being conducted at White Sands Missile Range.

The Committee on SST-Sonic Boom has three immediate goals (1) the development of advice on the planning and analysis of sonic boom tests, (2) examination and analysis of available

data on the sonic boom for the purpose of assisting in determining the feasibility of SST operations, and (3) the preparation of recommendations covering the direction and emphasis on research pertaining to the sonic boom problem.

The Committee first met in July 1964 and has been meeting at approximately four week intervals since then. It has been briefed on sonic boom tests, such as at Oklahoma City, and on Air Force and NASA research on the mathematics involved in calculating sonic boom characteristics and their relation to aircraft design and performance. Boeing Aircraft Company and Lockheed-California Company each made presentations to the Committee, and the work conducted by the Department of Commerce on the economics of the supersonic transport was described and discussed at a Committee meeting.

The Committee has recognized four major problem areas which it is using as the major sub-divisions of this report:

1. Generation and propagation of shock waves - the aeronautical aspects of the problem.

2. Effects of the sonic boom on structures and structural material.

3. Physiological effects of the sonic boom.

4. Behavioral response to the sonic boom.

Supporting this report are the following:

1. THE GENERATION AND PROPAGATION OF SONIC BOOM SHOCK WAVES prepared by Herbert A. Hutchinson, Wright-Patterson Air Force Base

2. ANATOMICAL AND PHYSIOLOGICAL EFFECTS OF IMPULSIVE PRESSURES IN AIR AND THEIR PROBABLE RELATIONS TO SONIC BOOMS prepared by D. H. Eldredge, Central Institute for the Deaf; Henning E. von Gierke, Wright-Patterson Air Force Base; and Milton A. Whitcomb, National Academy of Sciences, the members of an <u>ad hoc</u> Committee of

the Committee on Hearing, Bio-Acoustics, and Biomechanics.

3. LONG-RANGE STRUCTURAL RESPONSE RESEARCH AND TESTING PROGRAM prepared by an *ad hoc* Committee on Structural Response to SST-Sonic Boom of the Building Research Advisory Board, National Academy of Sciences. The members of this *ad hoc* Committee are as follows: John A. Robertson (Chairman), United States Gypsum Company; Russell B. Akin, E. I. DuPont de Nemours & Company, Inc.; F. J. Crandell, Liberty Mutual Insurance Company; Ben H. Evans, American Institute of Architects; John P. Gnaedinger, Soil Testing Services, Inc.; J. D. Gwyn, Libby Owens Ford Glass Company; James R. Simpson, Federal Housing Administration; E. George Stern, Virginia Polytechnic Institute; Robert B. Taylor, Structural Clay Products Research Foundation; J. Neils Thompson, University of Texas; William J. Youden, National Bureau of Standards; John I. Zerbe, National Lumber Manufacturers Association; Joseph H. Zettel, Johns-Manville Research Center; C. B. Monk, Structural Clay Products Research Foundation (Special Advisor); and Robert M. Dillon, Building Research Advisory Board.

GENERATION AND PROPAGATION OF SONIC BOOMS
THE AERONAUTICAL ASPECTS OF THE SONIC BOOM PROBLEM

The aeronautical aspects of the sonic boom problem is understood to mean the influence of the airplane parameter on the boom phenomenon and, conversely, the influence of boom requirements or limitations on the airplane design and its economic potentialities. With this in mind, answers have been formulated to the following specific questions:

1. Is the present state of the knowledge such that the essential characteristics of the sonic-boom phenomenon can be reliably predicted for a certain airplane configuration?

2. Is the state of the art of supersonic airplane design such that the economic consequences of limitation in intensity of the sonic boom can be reliably assessed?

Since the initiation of the work of the Committee, the large amount of background material which is available for formulating the answers to these questions has been reviewed. Needless to say, this work has been helped effectively by the presentations to the Committee and by the review work of the staff. Needless to say, also, that final and exhaustive answers to these questions cannot yet be made.

The State of the Knowledge

The gas-dynamic equations of motion, even for idealized conditions of a still atmosphere and simplified properties of air, are complicated and do not generally permit surveyable solutions except for certain restricted circumstances. That, in spite of these difficulties, the phenomena of the sonic boom and the more complicated theory of design of supersonic airplanes have reached a satisfactory agreement between theory and experiment is a tribute to the imagination and resourcefulness of the leaders of this field over the last decades. Certain specific developments

may be mentioned to illustrate these advances. The perturbation theory in which the velocity field, besides a uniform velocity in the direction of flight, has superposed upon it another field of small velocity components, is one of the important devices whereby the equations may be rendered linear. This, in turn, depends on the fortunate circumstance that the change of entropy across a shock can be neglected to a high order of accuracy for weak shocks. The presence of shock waves, even waves of the strength encountered in a sonic-boom phenomenon, may thus be taken into account with the aid of relatively simple theory of isentropic changes.

Over the years since the 1930's, this has led to a theory of lift and drag for airplane structures which has provided a rational basis for the design of airplanes, reaching from the subsonic to the hypersonic speed regimes.

In the present context the influence upon this theory of the understanding of the sonic-boom phenomenon is most relevant. In the gross picture the discontinuities and changes in sections of the airplane, together with its lifting surfaces as it moves through the still air, generate a system of shock waves (resembling the bow and stern waves of ships) which reaches out as a conical sheet with the airplane as its apex. The intersection of this sheet with the surface of the earth as it moves with the flight velocity produces the sonic-boom phenomenon. At some distance from the airplane the phenomenon generally takes the form of the characteristic N wave. The forward portion of the disturbance is a rapid compression - a shock wave; this is followed by a more gradual expansion, and then there is a second shock wave. The wave length, the distance between the two shocks, is related (as in surface ships) to the length of the airplane; but since the waves are not exactly parallel, the wave length is greater than the length of the airplane.

The shapes, positions, and strengths of the two shock waves at the ground, even in still air, actually depend on the detailed geometry of the airplane, for the waves are modified by every detail of the pattern of velocities around the body and wings. In principle, this detailed field could be computed for any given configuration, but the computation would be tedious, and fortunately it is not usually needed. In the hands of G. B.

Whitham a practical solution became possible by virtue of his intuitive insight; following M. J. Lighthill he postulated that the disturbances calculated for an idealized Mach line will hold to a close approximation when transferred to the actual Mach line, whose position can also be established by an approximate method. It is this theory, rationalized through the extensive work by many specialists in NASA and in several of the airplane companies, that now forms the basis for prediction of the wave form and intensity of the sonic boom. It accounts for the shock waves produced by both the lifting elements (wings) of the aircraft and its volume elements (body, nacelles, etc.). For aircraft at higher altitude, the part due to lift becomes the more important.

It is no reflection on the great achievements of this theory to emphasize its limitations. As described above it pertains to an aircraft in steady flight in an idealized atmosphere, at rest with respect to the earth, and having known pressure and temperature variations with altitude only. The effects of headwinds and tailwinds and their gradients can also be calculated to a good approximation. This theory has been confirmed by a number of experiments, both in wind tunnels and in flight. Needless to say, flight tests are not carried out under the idealized conditions envisioned by the theory, for the atmosphere and its winds are typically nonuniform. Quite apart from this complication, it is necessary to keep in mind the great difficulties of experimentation. Meaningful results can only be obtained if the observer or the instrumentation is accurately located with respect to the flight path. Fully reliable experimental results require that not only the pressure amplitude but also the shape of the impulse be recorded by sensitive and rapidly responding transducers.

In spite of these difficulties it is generally believed that the present theory essentially accounts for the sonic-boom phenomenon due to aircraft in steady flight in still air and in somewhat more realistic, but still idealized, models of the atmosphere. This contention cannot be proven with absolute certainty, because, as already mentioned, there are no such idealized atmospheric circumstances. When an attempt is made to make full allowance for all the variables of atmospheric influences, the theory becomes very complicated, although solutions may still be possible by means of extensive computer programs if necessary. We are doubtful that extensive calculations of this kind would be meaningful. They could hardly be useful as verifications of the theory, for the detailed, transient structure of

the atmosphere in which flight tests are carried out is never recorded. And as soon as we depart from standardized, non-turbulent models of the atmosphere (such as the ICAO standard atmosphere and the corresponding warm- and cold-day models) we are confronted with the absence of either accepted standards or statistical data of general significance.

This situation requires that experiments of sonic-boom phenomenon be interpreted statistically. The experimental series now available indicate that sonic-boom results appear as distribution curves of probabilities, the spread from predicted values apparently depending upon the degree of departure from the ideal atmosphere during the period of the test. Hence, if a sonic-boom overpressure of 2 lb/ft^2 is predicted by the available theory, the experimental results will indicate a spread, so that there will be a few observations up to 3 or 4 lb/ft^2. There will probably be statistical spread of overpressures in actual operations because of the focusing effects of accelerations and flight-path curvatures.

This conclusion makes it evident that the operation of a future SST will subject structures and people in the path of its shock waves to disturbances which can only be predicted by a combination of the gas-dynamic theory described above and statistical corrections. The most probable intensities can be predicted with accuracy, but the form of the distribution curve is still open to conjecture and can only be established by extensive experiments and measurements with supersonic airplanes. The analysis of existing test programs and the results of future test series will do much to firm up the estimate of the form of this distribution curve. It is thus necessary to recognize that limitations in the sonic boom can never be absolute; there will always be a small probability of more intensive shocks. As long as this must be the case, it is important that all estimates of public reaction to sonic booms be made with full appreciation of this situation.

It may also be important to point out that we do not know just what aspects of the sonic-boom phenomenon, e. g. what properties of the pressure-time signature, are in fact most important in determining annoyance to humans (or other animals), so that it may be rash to say that any gas-dynamic theory is adequate in this area. It seems possible that details of the signature (such as, perhaps, its oscillatory content in a certain

frequency range) that are almost wholly outside the scope of the still-air theory are significant in determining what people and animals "hear" as a boom passes. It is important that this be kept in mind in the planning of future experiments.

Influence Upon the Airplane Design

Limitations of sonic-boom intensity have presented the designers of the supersonic transport with a variety of problems that require insight into the entire array of components of the whole airplane system. The influence upon the requirements of the propulsion system turns out to be the most important.

Practically speaking, reductions in the overpressure on the ground during cruising can only be effected by increases in the flight altitude. Roughly, each 1/4 lb/ft^2 involves an increase in altitude of about 10,000 ft. At the higher altitudes the airplane must fly with a higher angle of attack; the resulting increase in induced drag requires more thrust from the engines.

The greatest overpressure usually occurs during the period of acceleration into the supersonic speed. The flight path must be such as to produce this maximum of boom intensity at sufficiently high altitude. But this period of acceleration through sonic speed is typically critical for the aircraft because of the great magnitude of transonic drag. The requirement for transonic acceleration at higher altutide clashes head-on with the fact that turbojet-engine thrust diminishes with increasing altitude; thus sonic-boom limitations demand over-dimensioning of the engines, with attendant increases of aircraft size and weight. At this point abnormal circumstances of the atmosphere enter the problem in their most severe form. If the temperature of the atmosphere is higher than normal, the propulsion system may not be adequate for this acceleration, and under these conditions the limits in overpressure may be exceeded. The only safeguard against such a contingency is to over-dimension the engine still further.

One of the important consequences of the sonic-boom limitation, therefore, is in its effect on the sizing of the engines. The relationships are exceedingly sensitive and present a typical example of a critical design problem, where an injudicious choice may lead to absurd consequences. The situation is best described

by a curve submitted to us by Boeing Aircraft Company which is reproduced from the paper by Kane and Sigalla (Figure 1). This shows that if a base point is established for an overpressure of 3 lb/ft^2 during climb, the engine size for an overpressure of 2 lb/ft^2 would have to be increased by about 10%. The gross weight of the plane would then be increased by about 5%. However, if the limit in overpressure were to be set a 1 3/4 lb/ft^2, engine size and gross weight would increase many-fold, and the economic characteristics of the airplane would be badly, perhaps catastrophically, compromised. A related study made by Lickheed California Company has led to the curves of Figure 2. Here the ordinate is annual earnings (before taxes and interest) per aircraft; the study was made for a series of Mach 3.0 supersonic transports of 213 seats. The results are typical. They show that limitations imposed on permissible sonic boom overpressure in the climb (calculated for steady flight in still air) can seriously reduce the earning capacity of the aircraft in domestic operation. Moreover, in international operation, where trip lengths are longer, the deleterious effect of sonic-boom limitations is more striking and occurs at larger values of the calculated overpressure. It should be emphasized that these effects on earning capacity were calculated by a simulation scheme for transport operations involving flights of various lengths, i.e., they have been averaged over a variety of trip lengths typical of domestic and international airline operations, respectively. In actual fact the effect of severe sonic-boom limitations can be more drastic in some operations. For example, limitation of calculated climb sonic boom overpressure to less than 2.0 pounds per square foot can make it impossible for certain aircraft to carry out the New York-to-Paris operation; this might render the aircraft totally unacceptable for transatlantic use, effectively reducing its earning power to zero, as far as some airlines are concerned.

This sensitivity of airplane efficiency and economy to sonic-boom limitations is the outstanding aspect of the whole problem. When these conclusions are viewed against the uncertainties introduced through turbulence and wind and velocity gradients and our uncertainties as to exactly what features of the phenomenon are responsible for damage to structures and for annoyance and discomfort to people and animals, the need for additional information becomes apparent.

Conclusions

1. The state of knowledge appears sufficient to predict with considerable accuracy the sonic-

boom phenomena for steady flight in still air or in various idealized atmosphere models involving head- and tail-wind gradients as well as temperature variations.

2. The state of the art of airplane design is therefore capable of developing the consequences of sonic-boom limitations that are specified in terms of the pressure-time signature on the ground under these conditions.

3. Sonic-boom limitations must be made with expectation of a certain statistical spread and will eventually have to cover a predictable probability of a range of intensities.

4. The principal sources of statistical spread in intensity are believed to be deviations of the aircraft from straight, steady flight and atmospheric phenomena, particularly turbulence, but including also other complex departures of the real atmosphere from the idealized models mentioned above.

5. It is imperative that further information be obtained concerning the significance of various features of pressure-time signatures in determining structural damage and annoyance to people and animals. Until such information is available, neither theoretical predictions of boom intensities nor statistical empirical information can be intelligently evaluated.

FIGURE 1

DESIGN PENALTIES

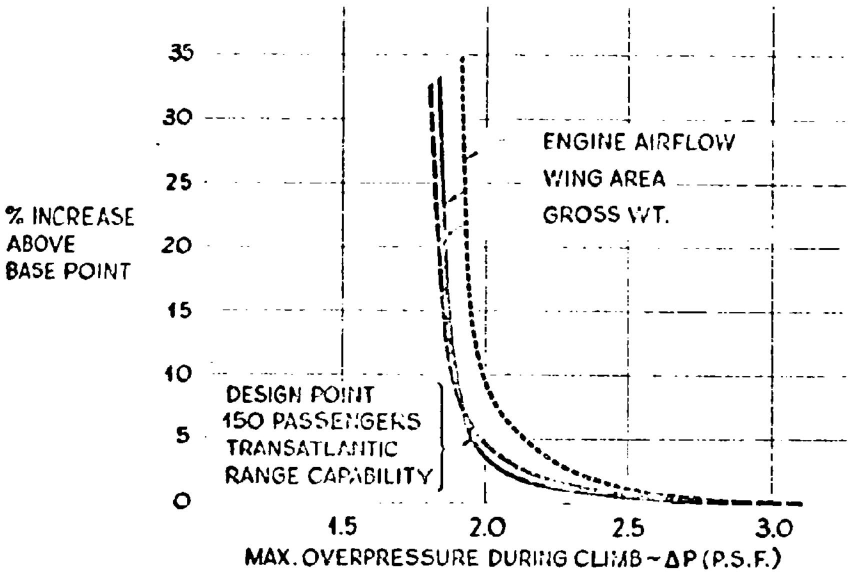
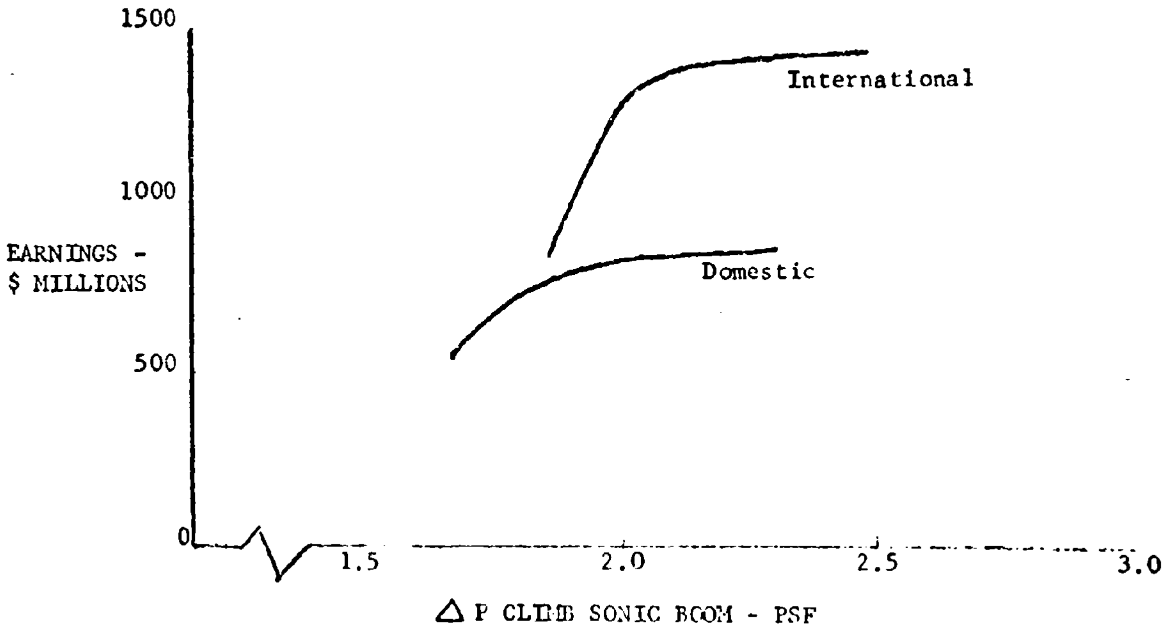


FIGURE 2

EARNINGS AND RETURN ON INVESTMENT
VS SONIC BOOM OVERPRESSURE



STRUCTURAL RESPONSE

The United States has hundreds of billions of dollars in its present inventory of buildings, bridges, utilities and installations of all kinds, and these will be affected, in some measure, by the sonic boom. The flight paths of commercial supersonic planes have been indicated by studies, and it is obvious that, unless flights are restricted to oceanic routes, a considerable part of the United States will experience many booms per day. For this reason, structural response must be carefully explored, as the Federal Aviation Agency is now doing. Furthermore, tests and observations must give assurance that no type of ground facilities will be affected to an unacceptable degree.

State of Knowledge

One- and two-story houses, which have now been partially explored, comprise about 28% of the nation's ground facilities. While tests of these are important, the large segment of facilities other than residential must be studied as to their component parts before complete assurance can be given on damage potentials.

As a result of experience to date, a wide variety of opinions--good and bad--have been expressed on the structural response to the sonic boom. While there is now much general knowledge of the effect of booms on ground facilities, there is not sufficient correlated information on enough types of installations to serve as a basis for this Committee's firm estimate of the situation. Every indication supports the belief that damage from properly controlled SST flights, at modest overpressures, will be minimal, and that good quality construction will not suffer appreciably; only by proper tests and experience can an adequate appraisal be made.

Test Program

Sonic Booms are now measured in pounds of overpressure per square foot, and ground level overpressures from the SST flights are now contemplated to be approximately 2 psf but with a probable spread of up to 3 or 4 psf due to atmospheric influences. (By comparison, overpressures from common sounds, such as the slamming of an automobile or house door, may approximate 3 psf.) To physical structures, materials, and equipment on the ground that are reasonably well built, such overpressures should not cause direct damage on either a one-time or on a repeated basis. However, as a "triggering" agent with brittle or initially stressed building components, the sonic boom can be expected to be troublesome.

Within many completed structures, particularly older ones, many of the brittle components--plaster, concrete, mortar, brick, ceramic tile, glass--are under stress induced by installation, by settling, or by wear and tear. Appearance of a structure, such as a home, gives little indication of the residual stresses it contains. At any time, due to supplemental strain from a slammed door, a stomped foot, a thunderclap, a gust of wind, ground-transmitted vibration from a passing truck, additional distortion, or a sonic boom, any brittle structural component already stressed near its limit may crack, break, or shatter. Since all completed structures do naturally contain stressed elements, it will be possible to predict only in a rough statistical manner, based on many experiences similar to the Oklahoma City tests, the frequency and extent of structural damage which will be caused by--or at least claimed against--the "triggering action" of sonic booms. After stresses have been relieved by cracking, it is impossible to determine accurately which of numerous possible supplemental stresses produced the triggering.

Triggering may very well affect natural features and man-made works other than buildings, and in this area less is known about the result of boom. Examples are snow slides, earthworks, and earth dams, on which, to date, tests have not been extensive.

Early in 1964, extensive tests were made in OKLAHOMA CITY, over a six-month period. Tests and instrumentation were concentrated on one-story houses, thus reflecting conditions o. only a portion of the residences of the nation and a far smaller fraction of other existing structures. Preliminary Oklahoma data furnished the Committee indicate that, as a result of the 1253 flights over the City, the amount of damage occurring was almost

negligible, and that the damage which did take place may well have been "triggered" or resulted from poor construction that was not in accordance with building codes.

Additional controlled testing was obviously required, in an effort to resolve some of the unknowns, and FAA set up the first phase at WHITE SANDS, New Mexico, with a program exposing 19 buildings, plus electronic equipment, to sonic booms from 2 pounds up to 20 pounds; such tests are currently under way so that preliminary major results will be known early in the year. Details will be available late in the Spring of 1965.

This initial test program had to be expedited with such vigor that time was not available to prepare completely the planning, structures, and building components that would make maximum use of the flights. As the first phase of a continuing test series, the Committee feels that it is se ving the excellent purpose of furnishing some highly basic--even though limited--information on structural response and on boom characteristics.

At the present time, the Air Force is flying supersonic training missions over parts of CHICAGO. While these flights are not meant to be "boom tests," they provide opportunity to observe overpressure variations, reflections, and possibly reinforcement from maneuvers.

Intended ground-level overpressures cannot be uniformly maintained at any prescribed amount, so any prescription will have to be regarded as nominal. Both Oklahoma City and White Sands measurements, as well as NASA programs, contribute some knowledge on the extent of variations. For example, in 2600 recordings at Oklahoma City, 11% of the flights exceeded the 2.0 psf intended overpressure and averaged 2.42 psf; 0.2% were 3.5 psf, or 175% of intended value, and less than 0.1% were 220% of the intended pressure.

The aeronautical and mathematical physics of generation and initial propagation of sonic booms appear to be well understood for relating any ground effects limitations back into aircraft design. But boom shocks are transmitted through the atmosphere, whose micrometeorology is not well understood nor scientifically predictable today. Shock pressure perturbations received through the air at various locations on the ground and striking structures cannot therefore be

predicted with great accuracy when the source of the shocks is an aircraft literally miles away. Both the form and amplitude of recorded sonic boom perturbations show relatively wide variations which seem to be attributable mainly to micrometerological factors.

At this stage of the science of meteorology, we will have to be content with statistical numbers and inherent variations when we speak of the "peak overpressures" or pressure-wave-versus-time shape of sonic boom pressure perturbations. Data collections from Oklahoma City, from White Sands--and possibly from Chicago--are producing, or could produce, significant statistical information bearing on this subject which can contribute to establishing the limits of boom signature variations. More of such statistical information, along with continuing study of measured responses of a wider variety of structures subjected to shock loading by measured sonic booms, may permit reaching economically important conclusions concerning relaxation of the rigid restrictions of 1.5 or 2 pounds per square foot maximum allowable, earth-level, peak "predicted" overpressures from an SST during level, constant-speed flight.

Conclusions

Test data available through December 1, 1964, show that sonic boom overpressure surges from planes flying at the altitudes planned for the SST will not seriously damage structures generally, and should have little or no effect on those that have been reasonably well designed and constructed. "Triggered" releases of stresses, or damage to poorly constructed, designed, or maintained buildings may be attributed to booms, and thus--with the possible nuisance of making the repairs--may well continue, through the public, to plague aviation. The Committee feels that, based upon present knowledge--and subject to the further tests to be made--overpressures of possibly 3 or 4 pounds per square foot should be acceptable for structures, bridges, utilities, and all ground installations in terms of both damage and damage claims.

Second-phase testing at White Sands was scheduled to start in mid-January, 1965. It is our belief that these tests should explore many buildings and components not yet exposed to controlled booms, but which could prove to be significant in our final appraisals. Complete planning, reconstruction, and new facilities--with as much agreement as practicable among construction industry authorities--are essential, even though this might mean some delay in the start of the second phase. As an indication of the benefits that might

have come from the use of more time in planning, the current use of modern plaster in the White Sands test--probably not properly cured on wood lath, and subjected to continual temperature change not normal in homes--could certainly have been avoided; the extensive cracking of this plaster, and ultimately the ceiling failure at 13.2 pounds, could lead to detrimental misunderstanding of boom effects.

Recommendations

The following recommendations are made on the basis that overpressures of 3 or 4 psf should prove to be acceptable, and with the understanding that some of these recommendations can be applied in PHASE II-B of the White Sands tests, while others will have to be developed in subsequent test programs:

1. Rebuild the plastered areas of PHASE II-A, in keeping with good practice, as identified by the Building Research Advisory Board; also,

    a. to facilitate cracking observations, omit paint from all plaster finishes. The occurrence of cracking can be determined readily by wiping such surfaces with a suspension of lamp black in kerosene;

    b. maintain interior temperatures in the buildings about as they would be under normal occupancy.

2. Develop tests in an urban area (such as Chicago) to get data which would indicate, with confidence, the variations in pressures due to reinforcing effects of reflected booms.

3. Determine pressure-time signature of the B-70 for a comparison with present theoretical calculations.

4. Test in an urban area large, flat, built-up roofs.

5. Test show windows of the skimpy designs that are normal to a great many retail and commercial buildings. Apply pressure, motion- and strain-sensing

devices, to determine magnitudes of movement and stress involved on the glass and frames.

6. Test the following under boom overpressures to develop thresholds of damage:

   a. Pneumatic controls

   b. Window wall sections with spandrel glass, such as Spandrelite

   c. Tempered (heat treated) glass doors, such as Herculite

   d. Precast concrete window wall

   e. Prestressed, precast concrete framing

   f. Large hung plaster ceiling area (some buildings have ceilings of 50,000 square feet)

   g. Porcelain metal panels

   h. Poured gypsum roof deck

   i. Gypsum plank roof deck

   j. New type single membrane roofing

7. Obtain data on overpressures due to level flights, maneuvers, and reflections, as they occur in Chicago.

8. Develop maneuvering overpressures at White Sands tests.

9. Develop a laboratory signature-simulation and structure-response technique and facility for repetitive laboratory simulation of signatures to permit extrapolation for many purposes that would be too expensive to study by overflights, e.g., fatigue/creep failures.

10. Test boom effect on natural features and man-made works, other than buildings or utilities, for "triggering"--if any.

On the basis of data from the above explorations, conduct any additional tests that appear to be desirable and essential.

PHYSIOLOGICAL EFFECTS

Sonic booms of intensities of 5 lb/ft^2 may be anticipated as the maximum that might be produced by SST planes in normal operation. Such booms will <u>not</u> cause direct injury to the normal human body. This conclusion is based on experience with explosions, including atomic bomb tests, with artillery fire, and with very powerful sonic booms produced in low-level flights. The margin of safety is very wide indeed. Dozens of individuals have been exposed to sonic boom overpressures from 35 up to 120 lb/ft^2 with no worse effect than momentary discomfort and slight temporary ringing and a sense of "fullness" in the ears.

The ear is the body structure most sensitive to and most easily injured by changes in air pressure, whether produced by explosions, sonic booms or sustained noise. Possible injuries are rupture of the drum membrance and partial impairment of hearing. The margin of safety is so great, however, in regard to overpressure, that direct injuries from a single sonic boom must be considered incredible. The sonic boom is in a different class from sustained noise because of its extreme brevity. Its frequency of occurrence would be so low that cumulative effects on hearing can also be dismissed as negligible. There remains only the marginal possibility of an ill effect in an ear in which an artificial stapes has been placed surgically to restore hearing in otosclerosis. Such an artificial stapes might possibly be dislodged. The hazard should be no greater, however, than from minor blows or from jerks of the head.

Indirect or "Trigger" Effects

Sonic booms come without warning and are therefore more startling than most other varieties of intruding noises. Familiarity with sonic booms and the knowledge that they are to be expected more or less regularly greatly reduce the startle effect but do not eliminate it entirely. Startle reactions can certainly precipitate accidents and injuries. Plausible types of such accidents would include slipping on a ladder, an automobile collision due to distraction of a driver's attention, a surgeon's knife slipping, and so on. Rather less plausible would be the precipitation of a heart attack, a stroke or other sudden medical misfortune. Such events will sometimes occur at the very moment of a sonic boom, and the claim will be made that the boom was the cause, although the probability of an actual causal relation is extremely small.

Disturbance of Sleep

Disturbance of sleep, particularly the sleep of invalids, must be reckoned as a significant medical problem. The effects of repeated disturbance of sleep may be cumulative, particularly when emotional factors become involved. The "normal threshold" for disturbance of sleep by such sounds has not been determined, but certainly the intrusion of sonic booms into quiet hospital areas where patients are being deliberately sheltered from the stresses of daily living would not be desirable.

PSYCHOLOGICAL RESPONSE

It is generally accepted that the psychological response area is the most difficult of all sonic boom problems and contains the most elusive questions. There is little doubt that the more we can learn from tests and studies about the effects of the boom on people and animals, the better we can define and meet the problems. This is true in spite of the difficulty of devising tests that can measure psychological response in a meaningful manner, and that will reflect the chronic characteristics of booms which the population would actually face with operational SST's. It should, however, be recognized that the only way to obtain answers to many of the questions is through continuing, actual, full-scale experience with the SST or comparable airplanes.

There have been determined efforts to obtain data on psychological respons through such tests as those at St. Louis in 1962, and at Oklahoma City in 1964. The current White Sands tests may also provide some data on sleep disturbance. But neither of the latter two tests have yet been reported on in final form; the test of the effect on a population of continuing night booms is still in the planning stage; there has been no conclusive evidence on the effects of sonic booms on animals.

Thus this section of the Committee's interim report is primarily a statement of the problem. It is given under four headings (1) Public Acceptability; (2) Psychoacoustic Effects; (3) Legal and Insurance Aspects; and (4) Public Relations.

Public Acceptability of the Sonic Boom

Public reaction to a new experience will be determined by the properties of the new stimulus, the situation into which it is introduced, and the characteristics of the public.

The Stimulus. The basic dimension of a stimulus is its intensity. If the sonic boom were inaudible and had no discernible effects on people or property it would obviously create very little public reaction. We assume that as intensity increases, public reaction would also increase. Presumably

there is an area of tolerance in which the sonic boom is perceptible but acceptable, an area within which the sound of present jet aircraft barely falls. We assume that as the intensity of the sonic boom increased through this range, public objection would increase. We do not know the shape of this function. We may think of an upper limit of tolerance as the highest intensity of sonic boom which could be accepted without serious public reaction. We do not know what this intensity level is.

A second important dimension of a stimulus is its frequency. Here again, the relationship of public reaction to frequency is ambiguous. If a sonic boom were heard only once a month it would probably not create strong public response, unless it caused physical damage. We do not know whether some form of adaptation would occur at high frequency rates. People who live next door to train tracks get used to the noise and rattle. However, people who choose to expose themselves to such annoyances may not react in the same way as people who are exposed involuntarily. In the latter case the acceptability of the sonic boom may decrease as its frequency increases. If the physical or psychological effects of frequent sonic booms are thought by people to be cumulative, public reaction would no doubt increase with increased frequency.

Stimuli differ in psychological as well as physical qualities. They differ in meaning. A stimulus which has favorable associations in the public mind may be tolerated much more readily than one which does not. The sound of friendly aircraft during wartime may be a welcome one even though the actual auditory experience may be unpleasant. The taste of otherwise unpalatable medication is readily acceptable if it is associated with desired biological consequences. The sonic boom will be perceived quite differently by people for whom it has different meanings. To the real estate developer who associates it with new business enterprises in his city it may seem readily tolerable. To the fugitive from the noisy tension of city life it may signify a further invasion of privacy by an increasingly intrusive society. To most people it may have relatively little meaning and be perceived as simply a louder and more abrupt version of a kind of auditory disturbance to which they have long since grown accustomed.

<u>The Situation</u>. A stimulus is never perceived in isolation; its psychological effect is always mediated by the total stimulus situation within which it is enclosed. A sonic boom superimposed on a background of street noises or office clatter would be perceived as less intense than the same

objective stimulus in the quiet of the night. People may be more tolerant of a sonic boom if it occurs during a period which they expect to be stressful (the workday in a metropolitan office) than they would be during a time they regard as protected and private (the evening in the suburbs).

The Public. The most important fact about the public is its heterogeneity. People differ in their physiological sensitivity, in their ability to bear psychological tension, and in their readiness to take countermeasures against stimuli they find disagreeable. In a sense public acceptability is determined by the most reactive part of the population since it is difficult to ask any part of the public to suffer a stimulus which it finds obnoxious even though the bulk of the people do not find it disturbing.

People differ not only in their sensory acuity but in their ability to absorb psychological stress. It is apparent that many individuals live at a high level of psychological tension which leaves little latitude for additional pressure. These people may be regarded by some as weak or "neurotic" but they exist as a part of the population and we must reckon with the social cost of anything which might exacerbate their problems. We do not know, of course, how many people (if any) would find the addition of sonic booms to their daily experience disturbing to their mental equilibrium. The current figures on the epidemiology of mental illness in its more and less severe forms suggest that any significant addition to the tension-producing stimuli of "modern life" will push some fraction of the population beyond their limits of tolerance.

People differ not only in their capacity to bear psychological annoyance or stress but in their willingness to accept it without protest. There is undoubtedly a sizable part of the population who will "put up with" almost any kind of inconvenience which is imposed on them from above. They are passive in the face of authority; they comply with their environment rather than resist it. There are other people who are able to absorb new annoyances without serious psychological disturbance but are unwilling to do so and will take countermeasures to avoid it. What is acceptable to one part of the public is not acceptable to another.

While that part of the public which objects to innovations which it finds offensive may be small, it is likely to have high status and to be capable of making its objections heard. It is the uncommon rather than the common man who is likely to protest invasions of privacy, infringements of

privilege, or simple inconveniences. The uproar over music cum advertising in Grand Central Station did not come from the humble commuters who pass through that vault but from a handful of intellectuals, public officials, journalists, and various protectors of the public weal. Whether they are moved by great principles or simple selfishness, such people know how to make themselves heard and they are listened to.

Public Acceptability. By what criterion are we to judge whether the sonic boom is acceptable to the public? If we think in terms of the electorate and acceptability as being determined by a referendum majority we may learn something from the history of another recent technological development, fluoridation of public water supplies. Wherever this issue has come to a public vote it has stirred a storm of controversy, led by highly involved individuals on both sides, and in three out of four cases the proposal has been defeated.

It is not likely, of course, that the question of accepting supersonic aircraft will be submitted to a national referendum, although it is conceivable that local political units might in time attempt to take action against supersonic use of "their" air space. The criterion of public acceptability may instead be a moral one, on which national leadership will have to make a decision. Is it right to subject the population to the physical and psychological impact of the sonic boom if it is known to be obnoxious and damaging to some fraction of the population? If fluoridation could be shown to be lethal to one person in ten thousand it would be morally unacceptable even if it were harmless to the rest. The case of the sonic boom is less clear since it is not likely to be lethal to anyone but if it should be shown to be seriously disturbing to some small fraction of the population the question of the minority rights of these people would have to be considered.

Of course the ultimate criterion of acceptability of the sonic boom is likely to depend far less on moral imperatives than on political practicalities. The question becomes one of attempting to predict the political repercussions of the sonic boom. If the Federal Administration comes to believe that the values it sees in the SST Program would be more than offset by public irritation which might eventually be expressed in the voting booth or in other political reprisals it will obviously proceed slowly. If it believes it can educate the public to see the SST as an instrument of national defense and a mark of progress it may feel safe in moving ahead. In either case it will make its decision on the basis of a calculus of values and costs in which public reaction appears as a very uncertain term.

Psychoacoustic Effects

Psychological Acceptability. The psychological acceptability of sonic booms is difficult to assess. It is certainly increased by familiarity with booms, by the knowledge of their source and significance and by the knowledge that they are harmless. Booms are transient and do not interrupt conversations and radio programs like the noise of jet-plane fly-overs. Frequency of occurence and the time of day at which they occur will undoubtedly be very important factors. Complaints of young children being awakened from sleep must be anticipated. People will vary greatly in their psychological reactions. Some will certainly come to take booms for granted and accept the mild startle that they may feel. Others will become progressively more irritated by the booms, particularly if the booms are felt as well as heard or cause windows to rattle. People who dislike sonic booms may be more easily and profoundly disturbed than the average.

In order to make a rough estimate of the level of overpressure at which booms are likely to become unacceptable a series of psychoacoustic experiments is planned for the very near future at White Sands, N. M. A jury of observers will be asked to compare the "acceptability" or the "annoyance" of alternate sonic booms and subsonic jet-plane fly-overs. A broad guideline as to public reaction to sonic booms may be established in this way. Unfortunately, however, these comparisons cannot include the element of surprise which probably contributes greatly to the annoyance of the sonic boom. Also a systematic study of the disturbance of sleep is planned, and perhaps of the intensity of startle reactions. But even with these data the practical psychological effects will be hard to assess, and they become less easy to predict as we pass from the average individual to the unusual individual and finally to the group behavior of many individuals in a community.

Legal and Insurance Aspects

The problem of noise has always been present in the field of aviation - principally noise at airports. The problem will be aggravated by the SST, not alone at the airports but throughout its line of supersonic flight, and particularly under its acceleration-climb path.

It may be expected that the inauguration of supersonic flights by commercial aircraft will give rise to claims for damage to property alleged to be due to sonic booms. In the

light of the experience of the Department of Defense it also may be expected that many such claims will be for pre-existing damage and will be prompted by irritation arising out of exposure to the unaccustomed sound of sonic booms. This is not to imply that there will be a great many claims deliberately falsified. Rather such cases occur most frequently where a person, annoyed by booms to which he is not (and may never become) inured, closely examines glass and plaster in his abode and for the first time observes cracks which had previously been ignored. Air Force experience with claims is illustrated by the following table.

FISCAL YEAR	CLAIMS MADE	AMOUNT CLAIMED	CLAIMS APPROVED	AMOUNT APPROVED
1956	36	$ 12,220.03	21	$ 1,913.71
1957	372	157,100.45	286	18,907.85
1958	522	196,215.66	235	39,519.06
1959*	632	285,182.30	243	21,355.98
1960	681	107,767.94	227	20,263.22
1961	1,146	703,174.65	527	57,274.44
1962	3,092**	990,483.35**	1,451	132,370.25
1963	7,200	4,022,718.00	2,268	239,450.00
1964***	5,102	3,544,754.99	1,664	182,543.71
	18,783	$10,019,617.37	6,922	$713,598.22

NOTE:

* B-58A FIRST FLIGHTS IN NOVEMBER 1958

** ONE CLAIM FOR $19,000,000.00 NOT INCLUDED

*** THROUGH 30 JUNE. DOES NOT INCLUDE OKLAHOMA CITY TEST CLAIMS.

Also a report of a USAF - NASA - FAA 1961-1962 flight test program states that, in the range of overpressures from 0.4 to 2.3 psf, a maximum of 0.87 damage incidents per flight per million population occurred, and that the settlement value was $71 per claim ($57.57 per flight per million population). Pending the final results of the Oklahoma City tests these are the only data of this kind available. The Committee notes that the majority of these claims apparently were without merit, and that, despite a too liberal attitude toward damage claims, less than 10% of the total amount claimed was actually paid out.

Especially in the early stages of supersonic flying it will be necessary to investigate carefully all claims for alleged damage even though the great majority of such claims

presumably will be for relatively small amounts and the costs of investigation probably will appear to be disproportionate to the losses actually incurred. Ultimately, when and if the general public has become used to the sound of supersonic flying, claims might be confined to an occasional extraordinary boom, perhaps arising out of abnormal manouvering of the airplane.

The special problems the airlines must face with the operation of the SST emphasize the need for a technique or formula for the original setting of rates for insurance to protect airlines against damage and other claims. As experience is gained, the major problem may become one of reducing the cost of handling claims.

Public Relations

It is probable that there would be considerable danger in a full-speed-ahead course to proceed with the SST program without greatly increased efforts to explain the sonic boom to the public. This would not be in any sense a "campaign to sell the public on the SST", but rather a policy of presenting the facts to the public, of dispelling false ideas and unfounded fears, of urging the public to avoid premature conclusions based on fragmentary information rather than solid facts.

This policy would impose on those responsible for the direction of future tests the necessity for proper press handling and the opportunity they present to let the public know the facts and the best estimates of the future. In the case of tests over restricted and relatively non-populated areas, it would of course be possible to keep public information at a minimum. However, that is neither necessary nor desirable. Such a practice would result in inaccurate news-reports, and editorial resentment as an effort to "manage the news". It would be an opportunity lost to let the public know the facts about the sonic boom's characteristics.

The press visit to White Sands during the sonic boom tests in early December, and the preliminary press conference in Washington by FAA officials, are regarded as having promoted a much better understanding of the problem on the part of an important press group, with the general impression on the part of the visitors that "the sonic boom is not nearly as bad as we had expected".

Pilot Public Information Program. Since the Oklahoma City tests provided some evidence of public response in a city

in which there was not a great deal of public warning and preparation, a pilot public information program to inform the public in advance what to expect in the city selected for the next tests will be a useful source of new data.

Such a program would involve contacts with city leaders, editors and commentators to explain to them what is planned, to show them reasons why there should be no alarm or hysteria, and to indicate to them that these are scientific tests in various areas and not tests to determine at what point there will be physical damage to houses and other structures. Motion picture footage (the FAA is putting some sequences together now into a motion picture) if edited properly, would be useful in explaining the situation to members of groups representing leadership in the city. Leading citizens might wish to cooperate by making statements, supporting the necessity for testing as a means of assisting those charged with making decisions regarding the future of the SST program. The cooperation of radio and television could be enlisted for special events programs.

A Long-Range Program. Over the long range, it is considered to be important for these informative efforts to be continued by those agencies, organizations and commercial airline companies directly interested. For instance, it goes without saying that the military agencies would wish to show the necessity for the supersonic plane for national defense. In the commercial field, it is to be expected that the airlines will, if it is decided to proceed with the SST program, show the advantages as outweighing the objections, including steps taken to improve ground service to take full advantage of the fast SST "in-flight" schedules. The airframe manufacturers would undoubtedly be eager to show engineering and design steps to increase the safety efficiency, and total acceptability of the SST and to reduce sonic boom. Airlines and government agencies could show what they were doing to increase operational effectiveness through route changes and flying patterns, and architects and contractors might subtly indicate what they were doing to sound-proof and strengthen windows, houses and other buildings.

The Committee has no wish to suggest specific actions. The basic approach, it has been thought, should be to inform and educate opinion leaders, so they in turn would be able to interpret developments intelligently in their contacts, writings and speeches, and to develop attitudes sympathetic to the problem. This might involve, in addition to press coverage of newsworthy events, informational type letters to editors, columnists and other leaders; motion pictures and slide films for schools, organizations and luncheon clubs; TV-Radio material; information for public speakers.

Cooperation with education institutions and industrial organizations would be expecially important. In the latter classification, for instance, the Koppers Company a few years ago produced an excellent motion picture on the sonic boom, even though that company's direct interest in the problem was relatively small.

A Coordinating Group. The Committee believes there would be definite advantages in a continuing coordinating group in this general area, perhaps with a sub-group in the field of psychological studies and a second sub-group in the field of public approaches. These groups might include representatives of such interested agencies as the Federal Aviation Agency, the Civil Aeronautics Board, the military services, the Air Transport Association, individual airlines, airframe manufacturers and their association, and possible airline insurance companies.